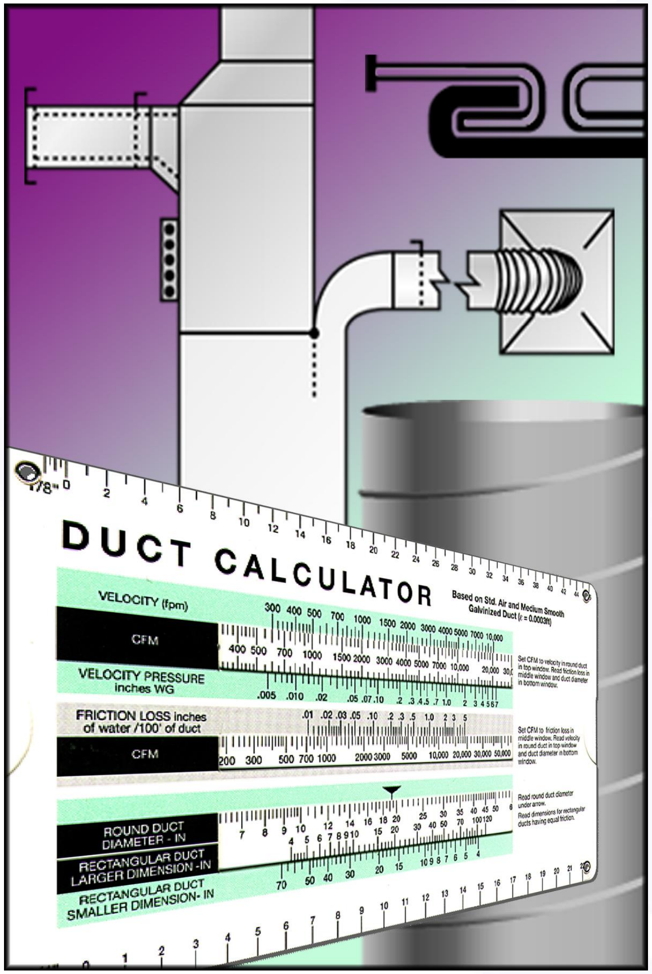
Technical Development Program



COMMERCIAL DISTRIBUTION SYSTEMS

Duct Design
Level 1
Fundamentals

PRESENTED BY:

Ray Chow

Sales Engineer

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BOOK MENU

Menu

Section 1 Introduction

Section 2 Duct Design Criteria

Section 3 Theory and Fundamentals

Section 4 Duct Design Process Steps

Section 5 Summary

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SECTION 1

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Introduction

BOOK MENU

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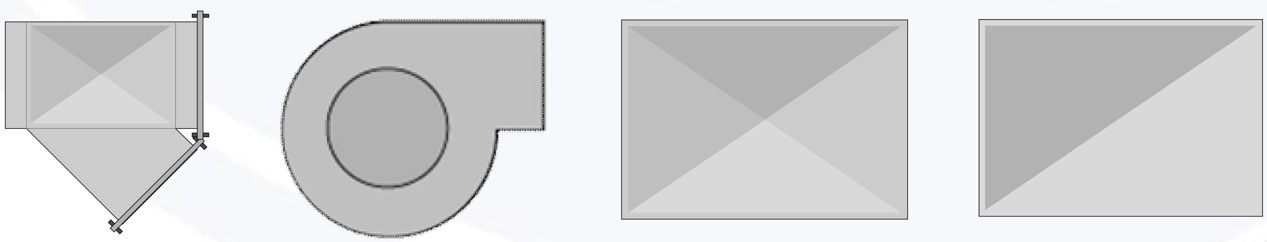
Objectives

- Apply Duct Design Criteria
- Understand Theory and Fundamentals
- Use Duct Design Process Steps
- Size Ducts with a Friction Chart or Calculator
- Work on an Equal Friction Example



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SECTION 2

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Duct Design Criteria

BOOK MENU

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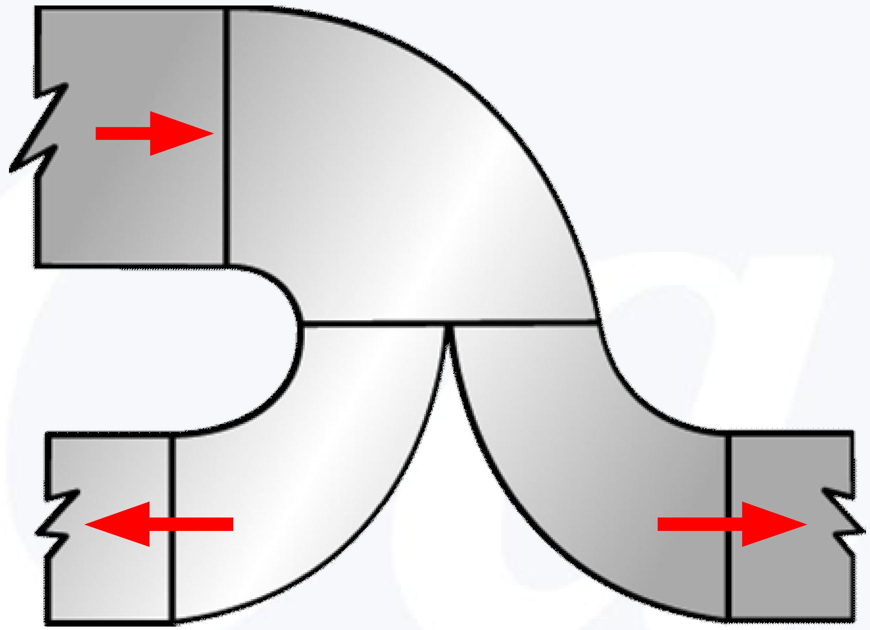
Duct

- Different shapes and sizes
- Different materials
- Air tunnel that allows air to move from one end to another
- Heating, cooling, ventilation and etc.

Duct Design Criteria

- Space availability
- Installation cost
- Air friction loss
- Noise level



- Duct heat transfer and airflow leakage
- Codes and standards requirements

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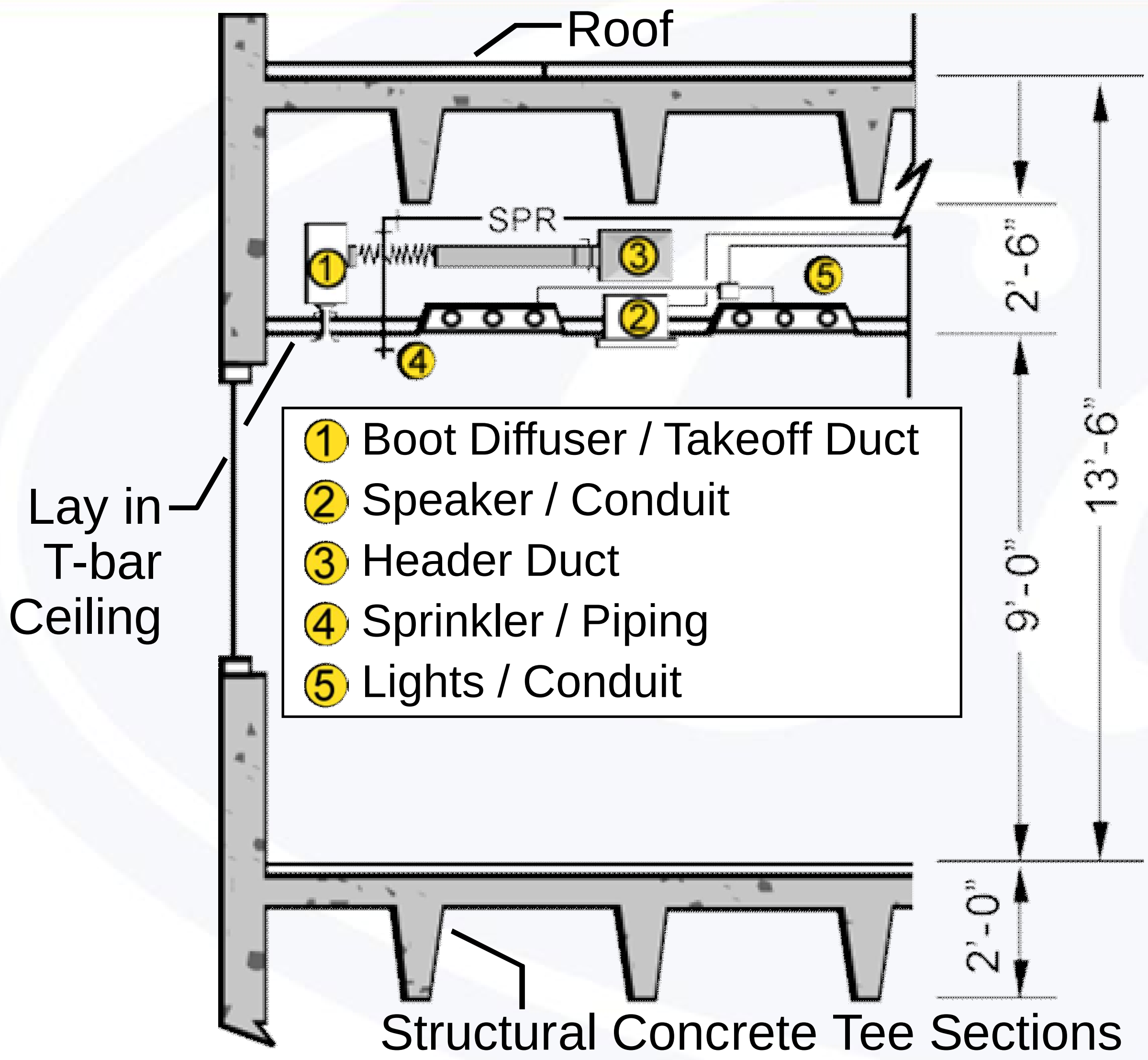
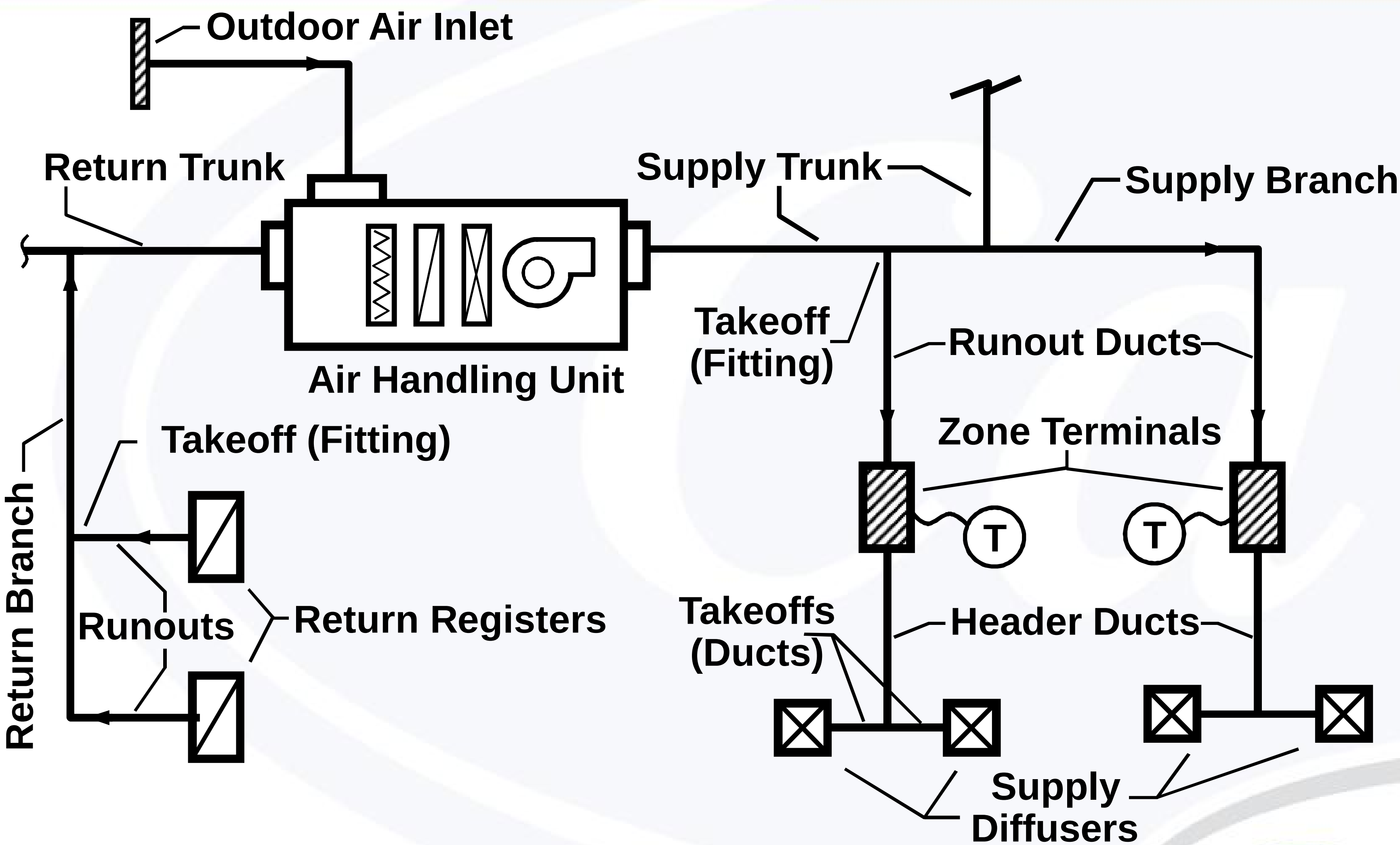
Fitting in the Ductwork

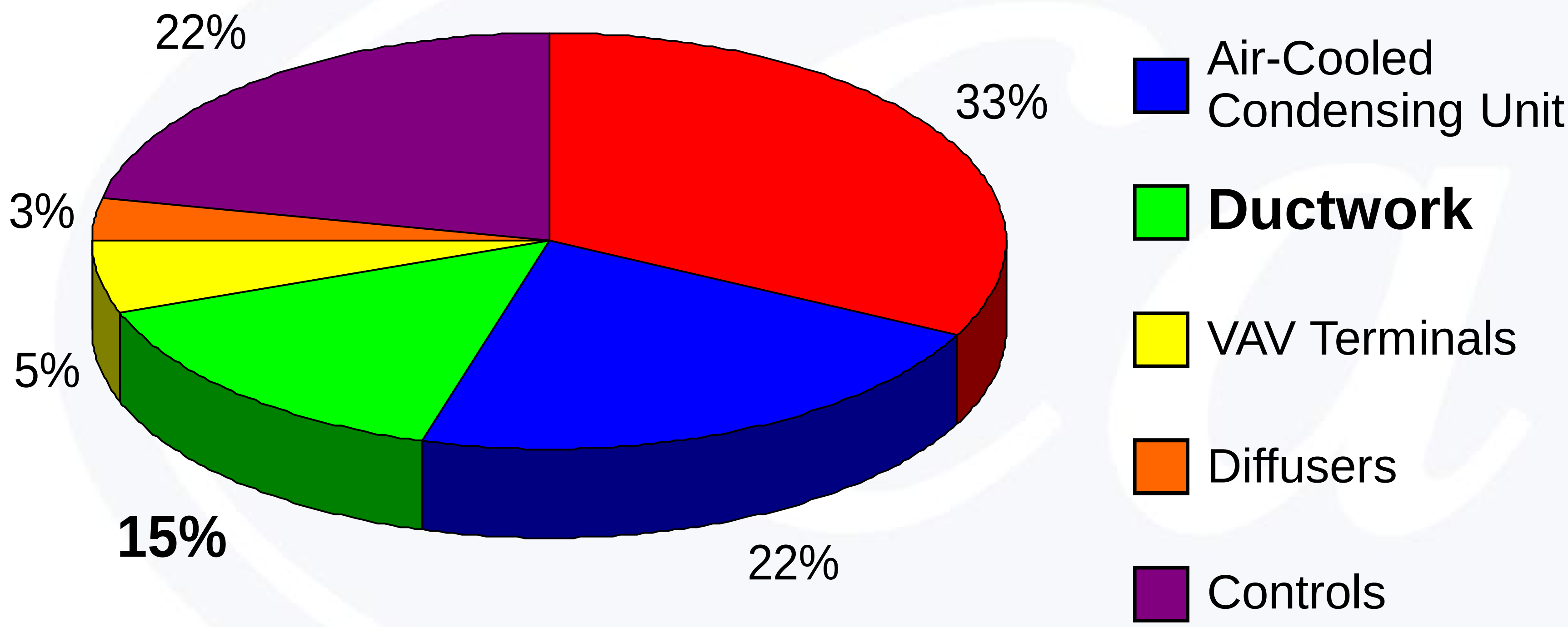


Duct Terms



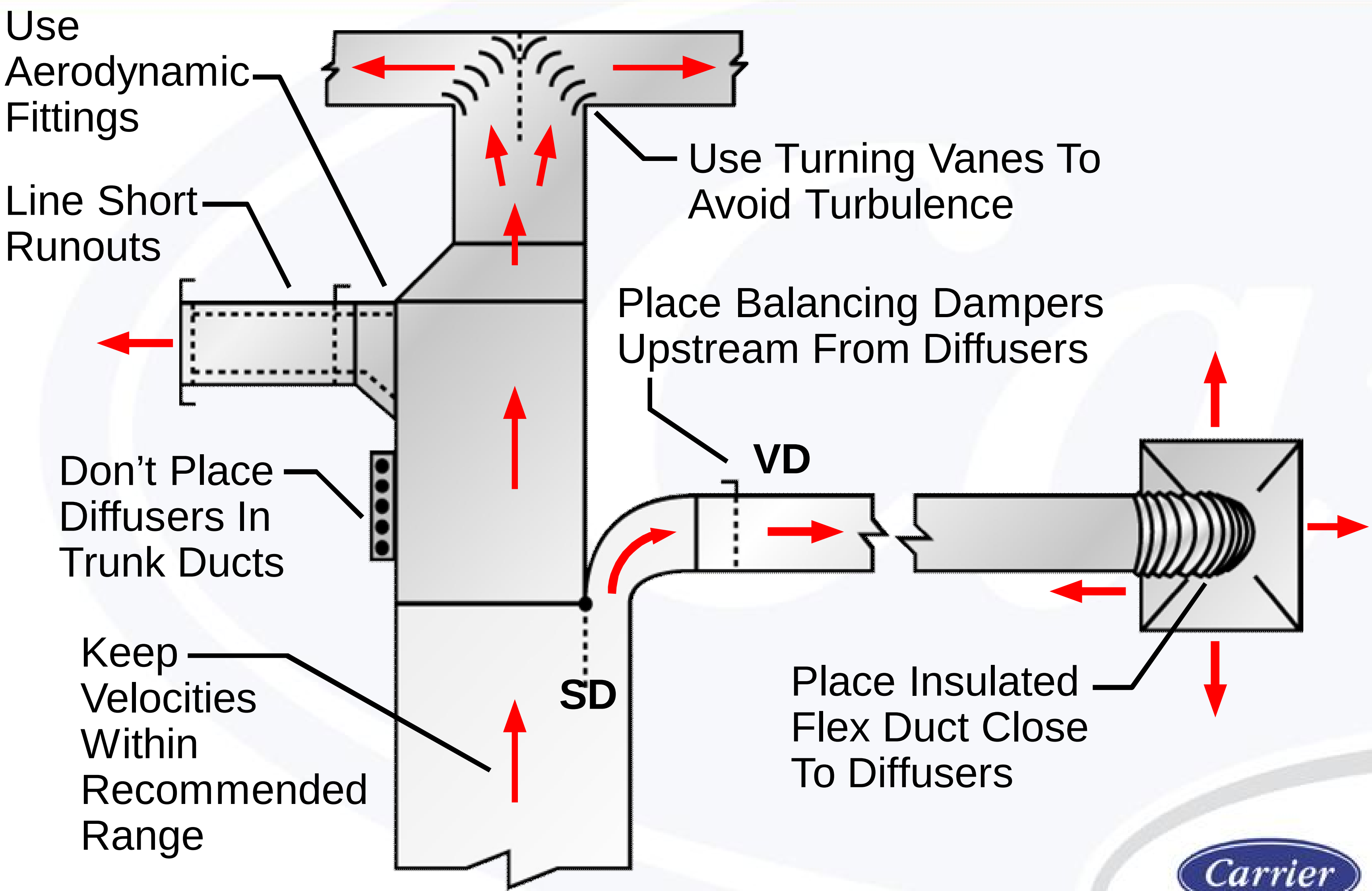
Outdoor Air Inlet
Return Trunk
Supply Trunk
Supply Branch
Air Handling Unit
Takeoff (Fitting)
Runout Ducts
Zone Terminals
T
T
Takeoff (Fitting)
Return Branch
Runouts
Return Registers
Takeoffs (Ducts)
Header Ducts
Supply Diffusers

Ductwork Portion of HVAC Costs



Cost based on DX Packaged Split VAV System

Limit Noise Levels



Sealing Ductwork

Minimum Duct Seal Level

ASHRAE 90.1
Table 6.2.4.3A

Duct Location	Duct Type			
	Supply		Exhaust	Return
	≤ 2 in. w.c.	> 2 in. w.c.		
Outdoors	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces * *	C	B	B	C

Duct Seal Levels

ASHRAE 90.1
Table 6.2.4.3B

Seal Level	Sealing Requirements *
A	All transverse joints and longitudinal seams, and duct wall penetrations. Pressure-sensitive tape shall not be used as the primary sealant.
B	All transverse joints and longitudinal seams. Pressure-sensitive tape shall not be used as the primary sealant.
C	Transverse joints only

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Codes and Standards Requirements

- **Building Code** deals mostly with life safety issues
- **Mechanical Code** addresses construction and installation
- **Energy Conservation Code** directs designers to create systems that meet insulation, leakage, and static pressure requirements

SECTION 3

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Theory and Fundamentals

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BOOK MENU

Basic Definitions

- Cfm: measurement of airflow in cubic feet/min
- Fpm: velocity or speed of air flow in feet/min
- Sq.ft: cross-sectional area

Theory and Fundamentals

- CFM = fpm x cross sectional area
- 1000 CFM = 1000 fpm x 1 sqft.
- 1000 CFM = 500 fpm x 2 sqft.

- Velocity(A) * Area(A) = Velocity(B) * Area(B)
- 1000 fpm x 1 sqft. = 500 fpm x 2 sqft.

Theory and Fundamentals

Conservation of mass

- air mass is neither created nor destroyed
- CFM (all inlet) = CFM (all outlet)

Theory and Fundamentals

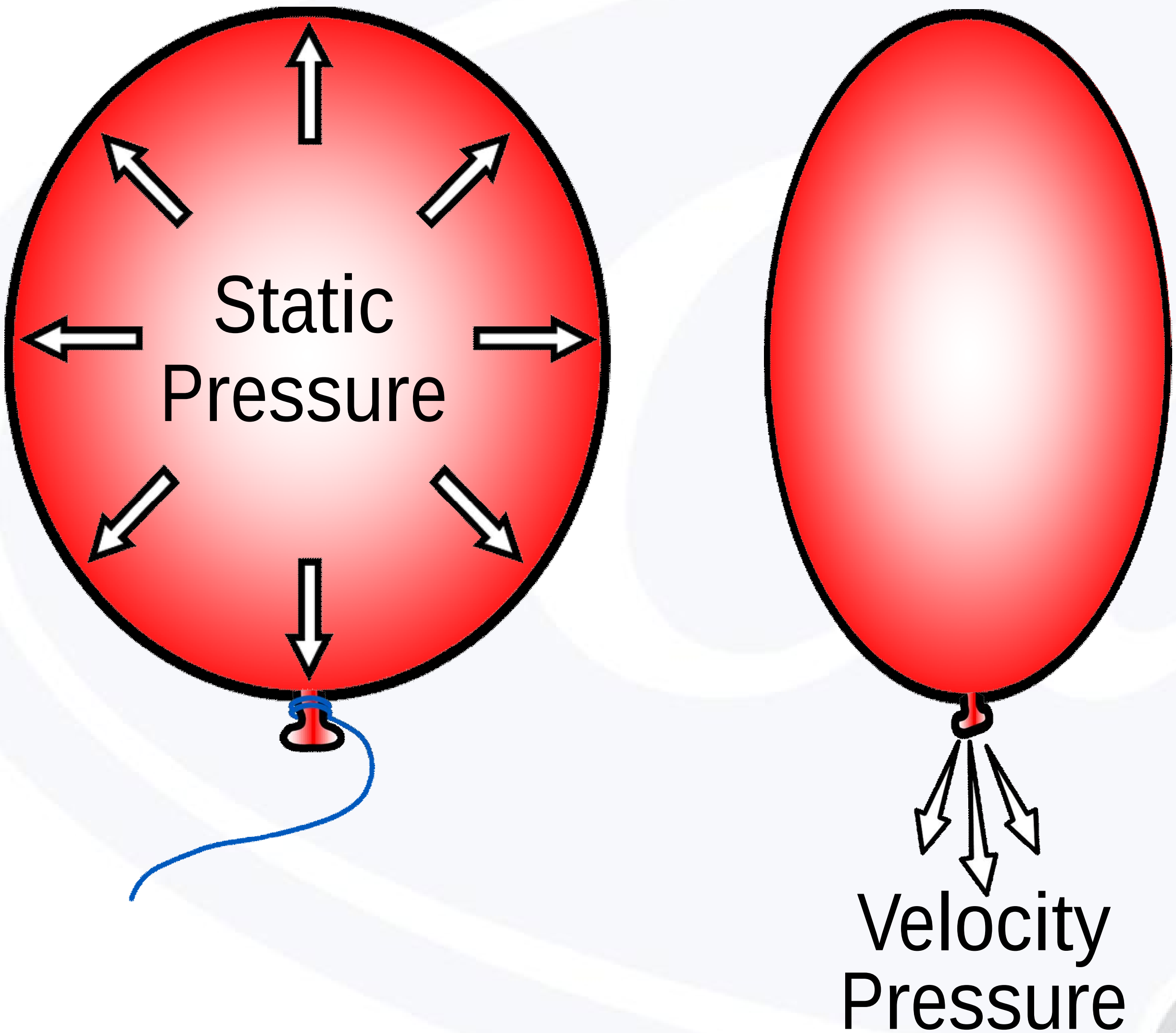
Conservation of energy

- Energy cannot be created or destroyed, only change from one form to another

Bernoulli's Law

- When there is a change in velocity there is a corresponding and inverse change in static pressure

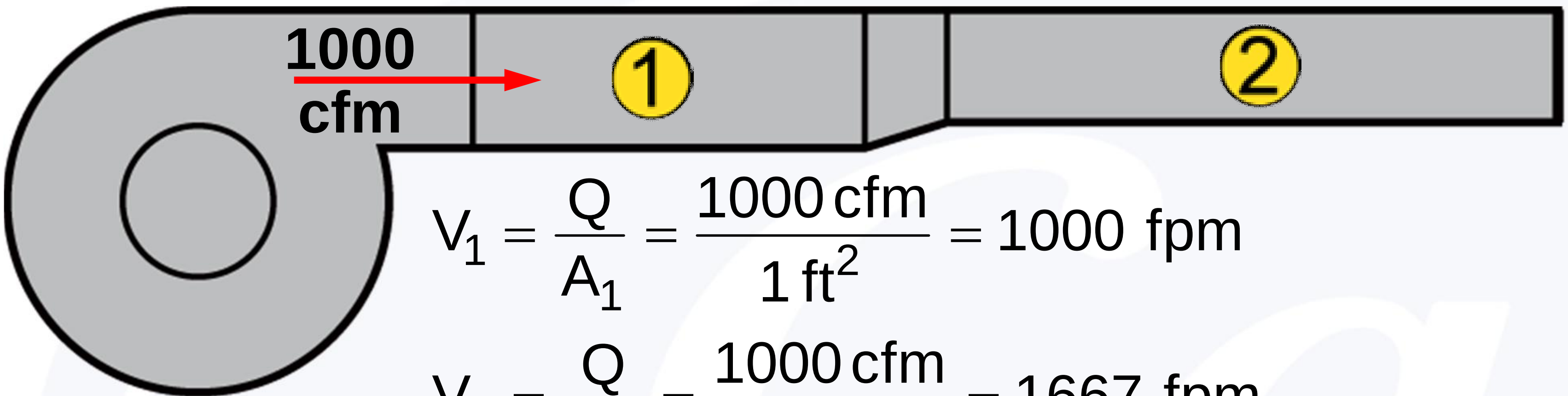
Static Pressure vs. Velocity Pressure



Theory and Fundamentals

- Total Pressure = Static Pressure + Velocity Pressure

Velocity Pressure Conversion



$$V_1 = \frac{Q}{A_1} = \frac{1000\ \text{cfm}}{1\ \text{ft}^2} = 1000\ \text{fpm}$$

$$V_2 = \frac{Q}{A_2} = \frac{1000\ \text{cfm}}{0.6\ \text{ft}^2} = 1667\ \text{fpm}$$

$$\text{VELOCITY PRESSURE} = P_V = \left(\frac{V}{4005} \right)^2$$

$$P_{V1} = \left(\frac{1000}{4005} \right)^2 = 0.062\ \text{in. wg}$$

$$P_{V2} = \left(\frac{1667}{4005} \right)^2 = 0.173\ \text{in. wg}$$

Factors Affecting Friction Loss

- Air Velocity
- Duct Size and Shape
- Duct Material Roughness Factor
- Duct Length

Duct and Design Velocities

RECOMMENDED & MAXIMUM DUCT VELOCITIES RANGES

Designation	Schools, Theaters & Public Buildings
Fan Outlets	1300 – 2200
Main Ducts	1000 – 1600
Branch Ducts	600 – 1300

Velocities are for net free area.

DESIGN VELOCITIES FOR HVAC COMPONENTS

Louvers	- Intake	400 fpm
	- Exhaust	500 fpm
Filters	- Electrostatic	150-350 fpm
	- HEPA	250 fpm
	- Bag / Cartridge	500 fpm
	- Pleated	750 fpm
Heating Coils	- Steam / Water	500-1000 fpm
Cooling Coils	- DX / Water	400-500 fpm

Effects of Shape, Ducts of Equal Area

All ducts = 9 sq ft

Duct	Aspect Ratio	Perimeter (ft)	Ratio of Perimeter to Area	Equivalent Round Duct (in.)	Friction At 15,000 cfm (in. wg / 100' EL)
40.7 in. dia.	1:1	10.7	1.18:1	40.7	0.070
3 ft × 3 ft	1:1	12	1.33:1	39.4	0.086
2 ft × 4.5 ft	2.3:1	13	1.45:1	38.7	0.095
1.5 ft × 6 ft	4:1	15	1.67:1	37.2	0.113
1 ft × 9 ft	9:1	20	2.22:1	34.5	0.156

Surface Roughness of Ducts

DUCT MATERIAL ROUGHNESS MULTIPLIERS		
For internal ductwork surfaces other than smooth sheet metal, multiply equivalent lengths by:		
DUCTWORK DESCRIPTION	**MULTIPLIER**	
	SUPPLY	**RETURN**
Rigid Fiberglass – Preformed Round Ducts – Smooth Inside	1.0	1.0
Rigid Fiberglass Duct Board	1.32	1.30
Duct Liner – Airside has Smooth Facing Material	1.32	1.30
* Flexible Metal Duct (Straight Installation)	1.6	1.6
Duct Liner – Airside Spray - Coated	1.9	1.8
* Flexible, Vinyl-Coated Duct with Helical Wire Core (Straight Installation)	3.2	3.4

* Flexible duct multipliers assume that the duct is installed fully extended.

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Recommended Friction Rates (*f*)

Ductwork	Friction Rate Range (in. wg / 100 ft EL)
Pressure Classes ½, 1, 2	0.10 to 0.15
Pressure Class 3	0.20 to 0.25
Pressure Classes 4, 6, 10	0.40 to 0.45
Transfer Air Ducts	0.03 to 0.05
Outdoor Air Ducts	0.05 to 0.10
Return Air Ducts	80% of above supply duct values

Notes:

1. Higher friction rates should only be used when space constraints dictate.
2. Using higher friction rates permits smaller ducts but raises horsepower (energy) and velocity (noise).
3. Maximum aspect ratio is 4:1 unless space constraints dictate greater aspect ratios.
4. When diffusers, registers, and grilles are mounted to supply, return, and exhaust ducts, velocities should not exceed 1500 fpm or noise will result.

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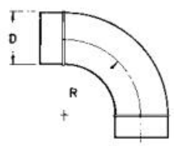
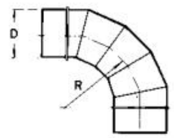
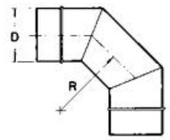
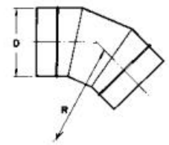
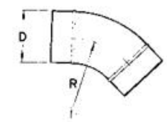
Fitting Losses

- Equivalent Length (EL) Method – converts fittings to straight duct (similar to piping)
- Dynamic Loss (C_V) Method – uses coefficients x velocity pressure

Fitting Losses

Duct Design Book Table 6 and 7

ELBOW DIAMETER (in.)	90° SMOOTH  R/D = 1.5	90° 5-PIECE  R/D = 1.5	90° 3-PIECE  R/D = 1.5	45° 3-PIECE  R/D = 1.5	45° SMOOTH  R/D = 1.5
	ADDITIONAL EQUIVALENT LENGTH OF STRAIGHT DUCT (FT)				
3	2.3	3	6	1.5	1.1
4	3	4	8	2	1.5
5	3.8	5	10	2.5	1.9
6	4.5	6	12	3	2.3
7	5.3	7	14	3.5	2.6
8	6	8	16	4	3
9	—	9	18	4.5	—
10	—	10	20	5	—
11	—	11	22	5.5	—
12	—	12	24	6	—
14	—	14	28	7	—
16	—	16	32	8	—
18	—	18	36	9	—
20	—	20	40	10	—
22	—	22	44	11	—
24	—	24	48	12	—

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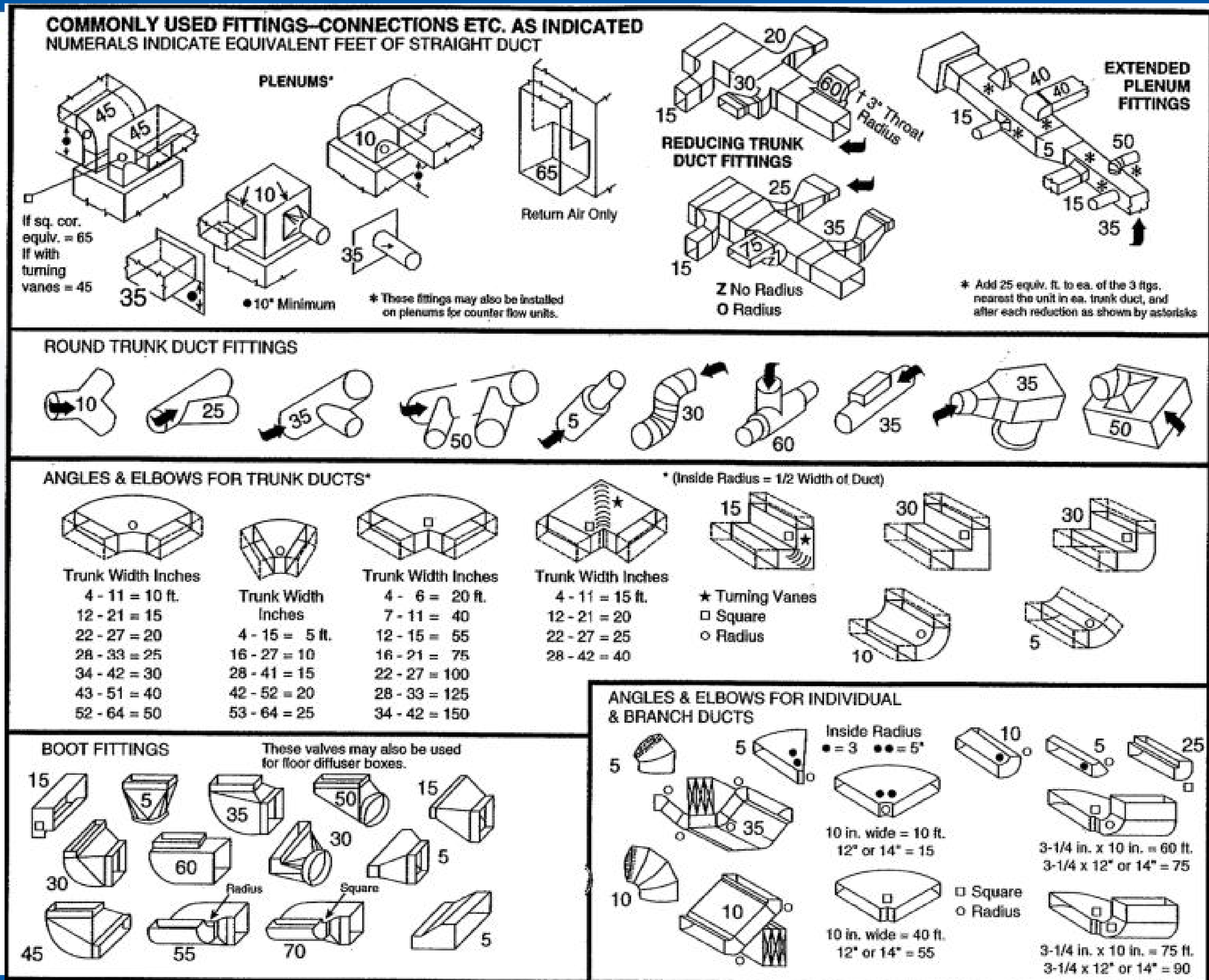
Fitting Losses



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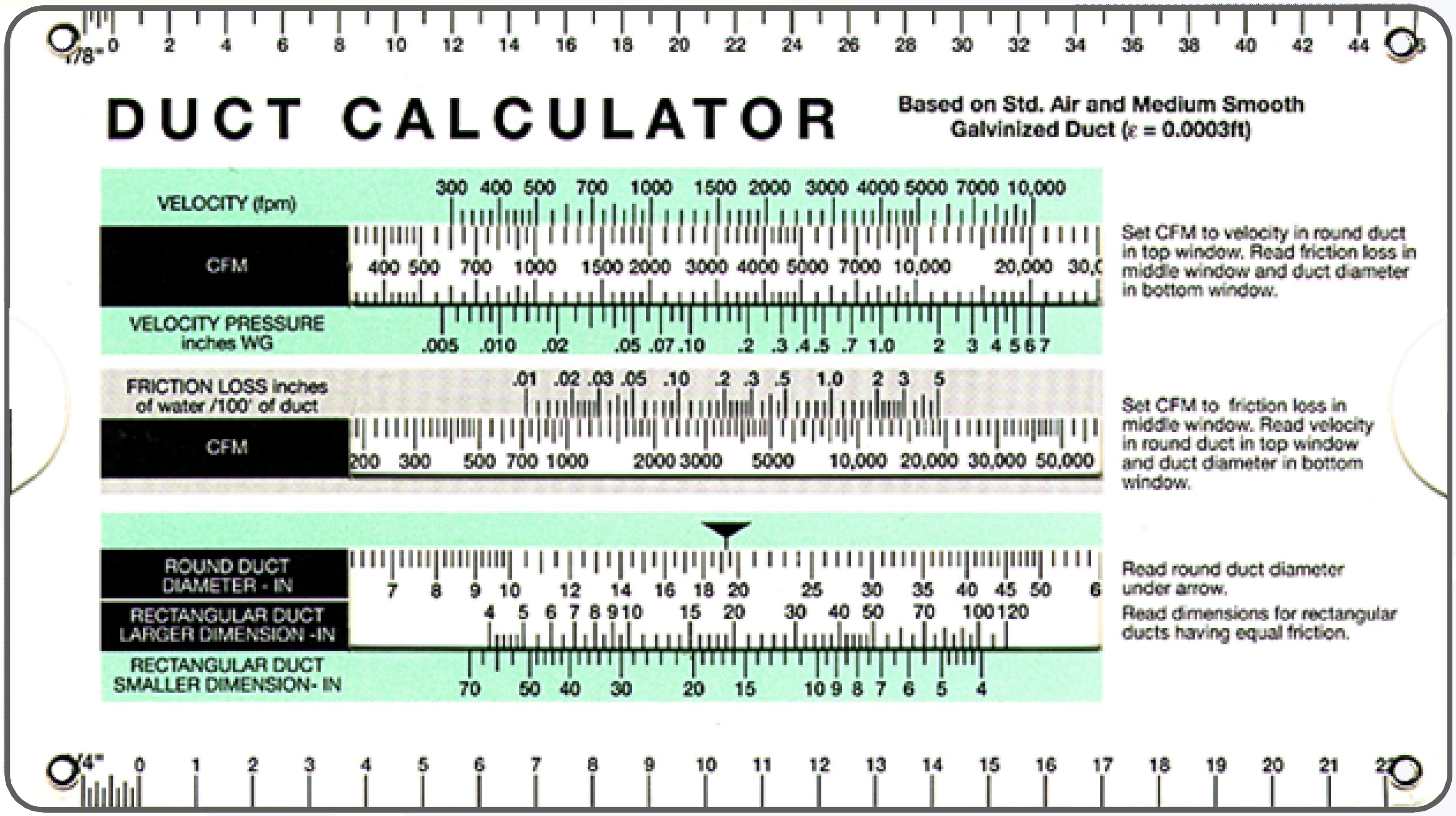
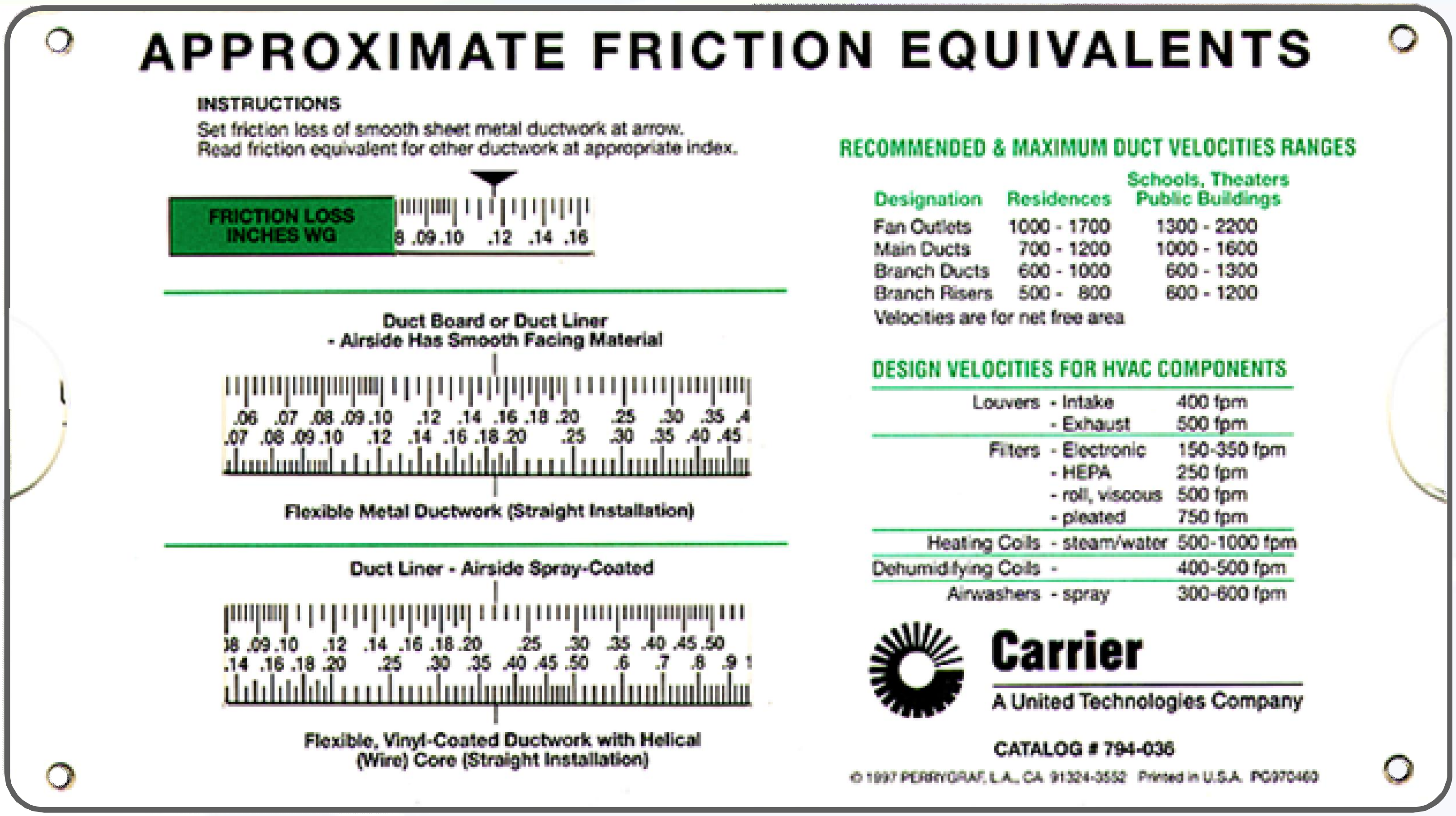
Break

Sizing with the Duct Calculator



Duct Calculator (reverse)



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Duct Calculator Scales

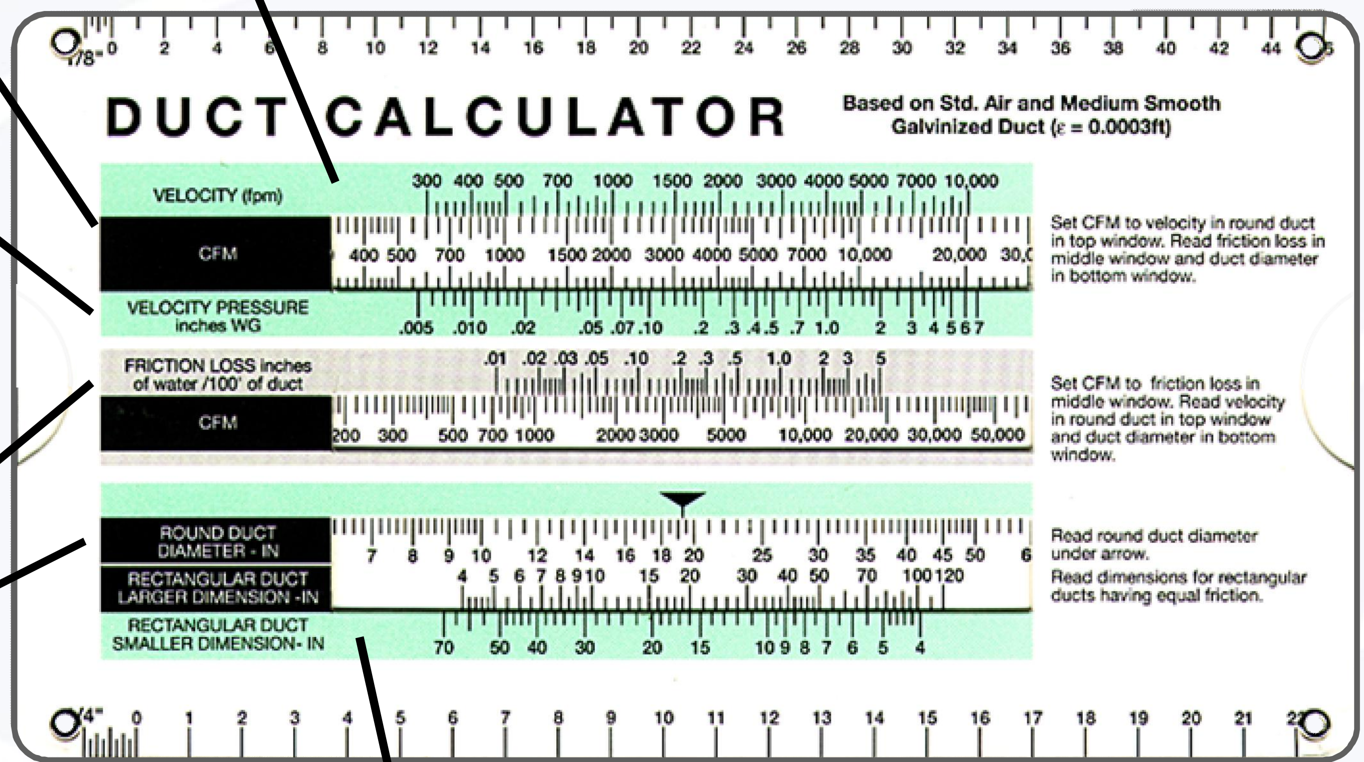
cfm (airflow)

Velocity Pressure

Friction Loss

Round Duct Diameter

Velocity Scale



Equivalent Rectangular Duct Sizes

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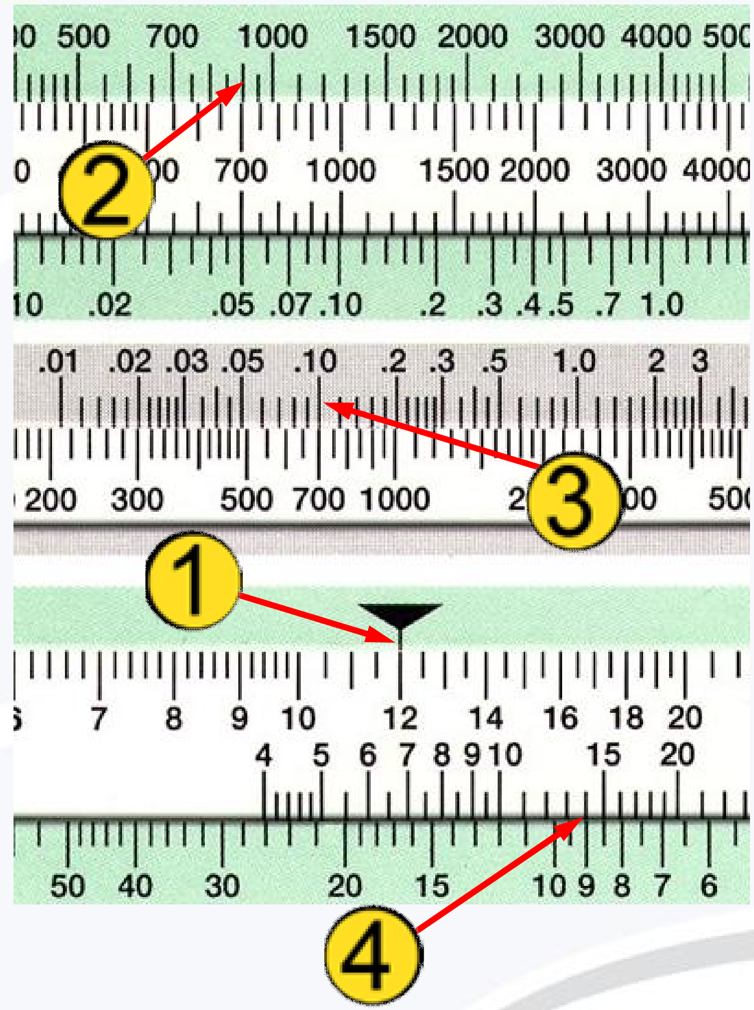
Duct Friction Loss Calculation Example

Given: 12” round duct with 700 cfm flow rate

Determine: Velocity, friction loss and possible rectangular sizes (in even number increments)

1. Line up 12” with pointer
2. Read velocity (900 fpm)
3. Read friction loss (0.10 in. wg/100’ EL)
   Possible rectangular sizes: 16” x 8”, 12” x 10”, etc.
4. 14” x 9” rectangular duct



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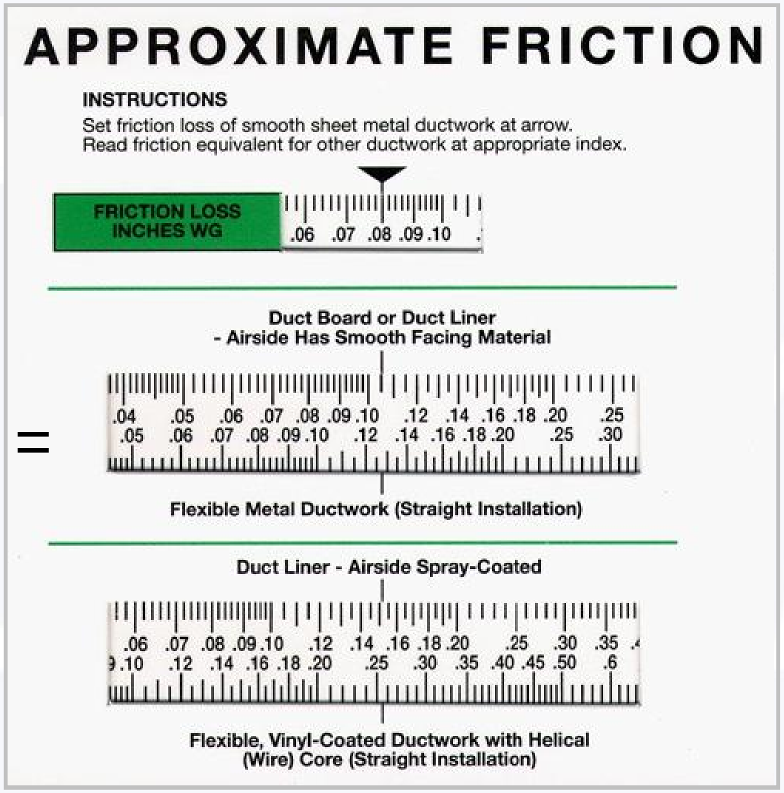
Conversion of Friction Loss Factor

Given: Friction loss for sheet metal duct = 0.08 in. wg

Determine: Friction loss for other duct materials

- Duct board = 0.105 in. wg
- Metal flex (installed straight) 0.13 in. wg
- Duct liner with airside spray coating = 0.15 in. wg
- Flexible, vinyl-coated duct (flex) = 0.26 in. wg

=



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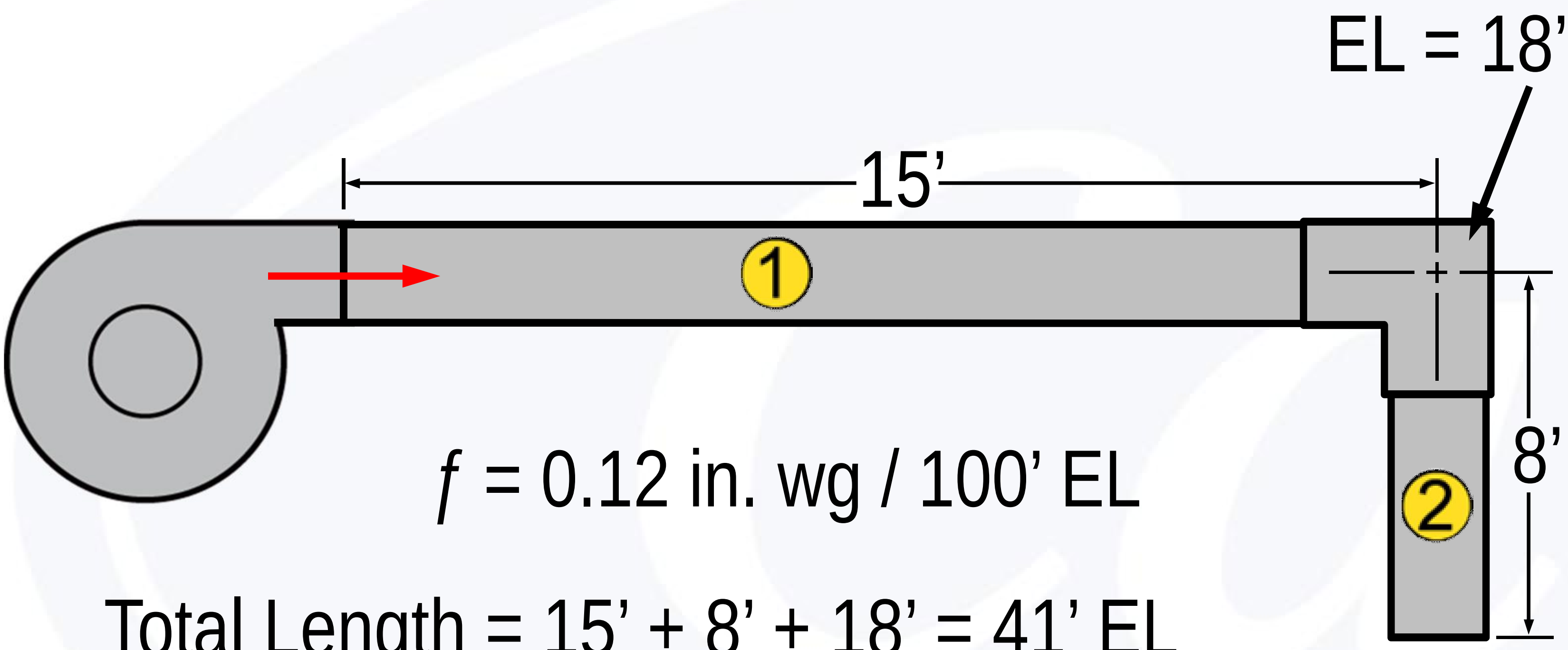
Using Equivalent Length



f = 0.12 in. wg / 100' EL

Total Length = 15' + 8' + 18' = 41' EL

Duct Pressure Loss = f ∗ EL / 100'

= 0.12 in. wg ∗ 41'/ 100'

= 0.049 in. wg

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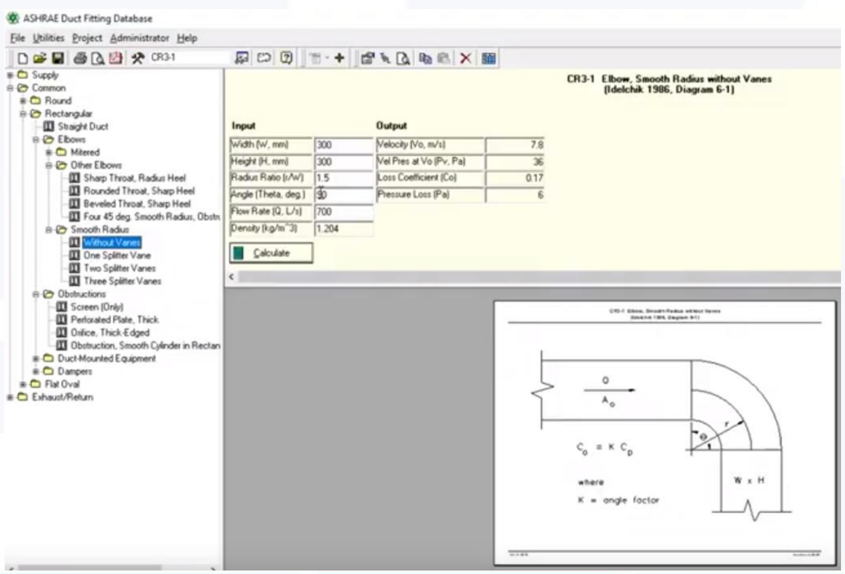
Duct Sizing Methods

- Equal Friction
- Static Regain – for sizing with software
- Other Methods



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SECTION 4

DUCT DESIGN LEVEL 1 FUNDAMENTALS

Duct Design Process Steps

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Duct Design Process Steps 1- 4

1. Determine Number of Zones
2. Perform Heating and Cooling Estimate
3. Determine Room / Zone Airflow Quantities
4. Select Duct Material, Shape, and Insulation
5. Layout Ductwork from AHU to Diffusers
6. Summarize Airflows and Label Ducts
7. Size Ducts from Fan Outlet to Diffusers
8. Calculate Air System Pressure Losses
9. Select Fan and Adjust System Pressures

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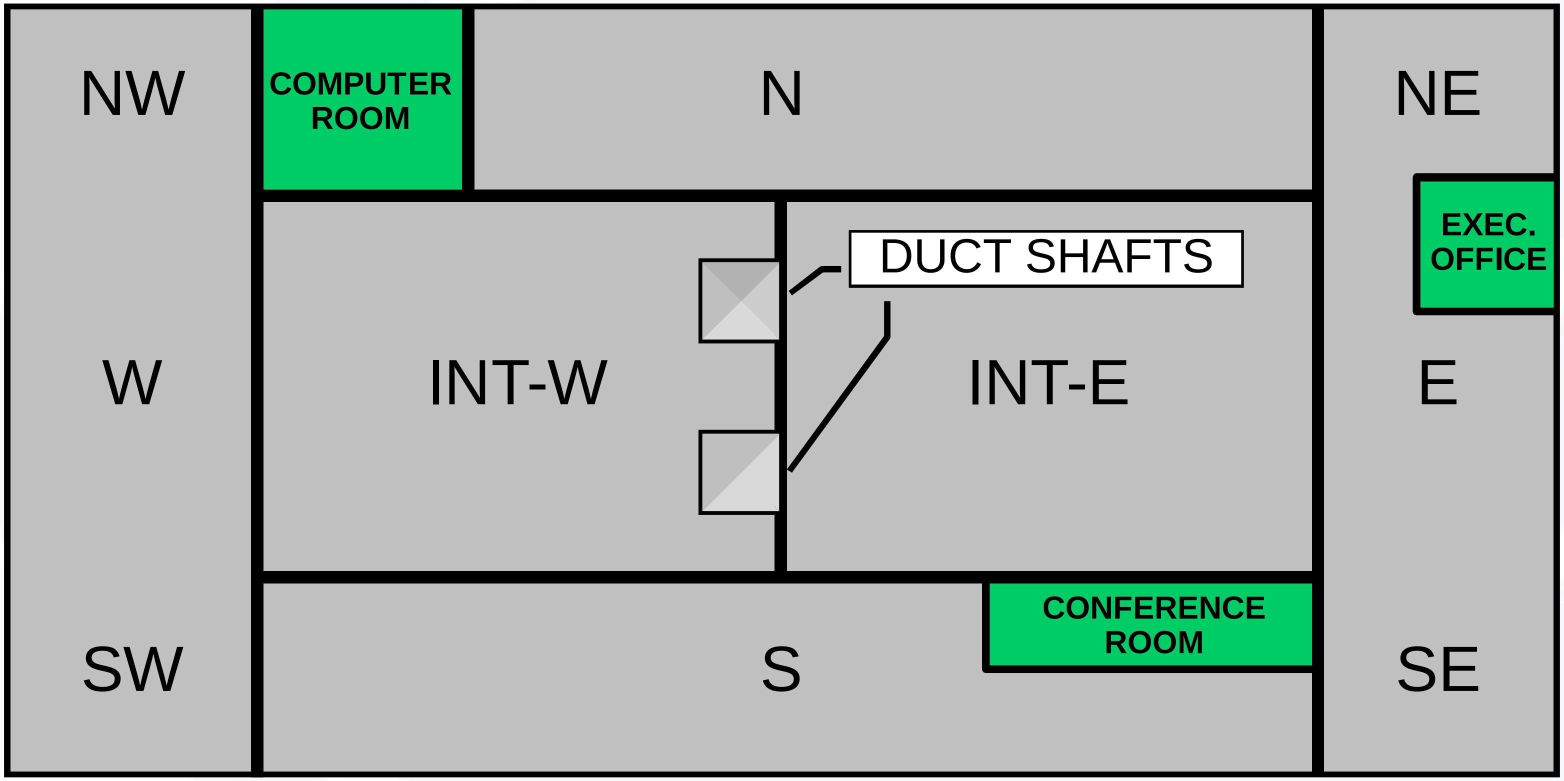
Design Step 1

Determine Number of Zones



- Basic Zones of Similar Loads
- Unique Sub-Zones

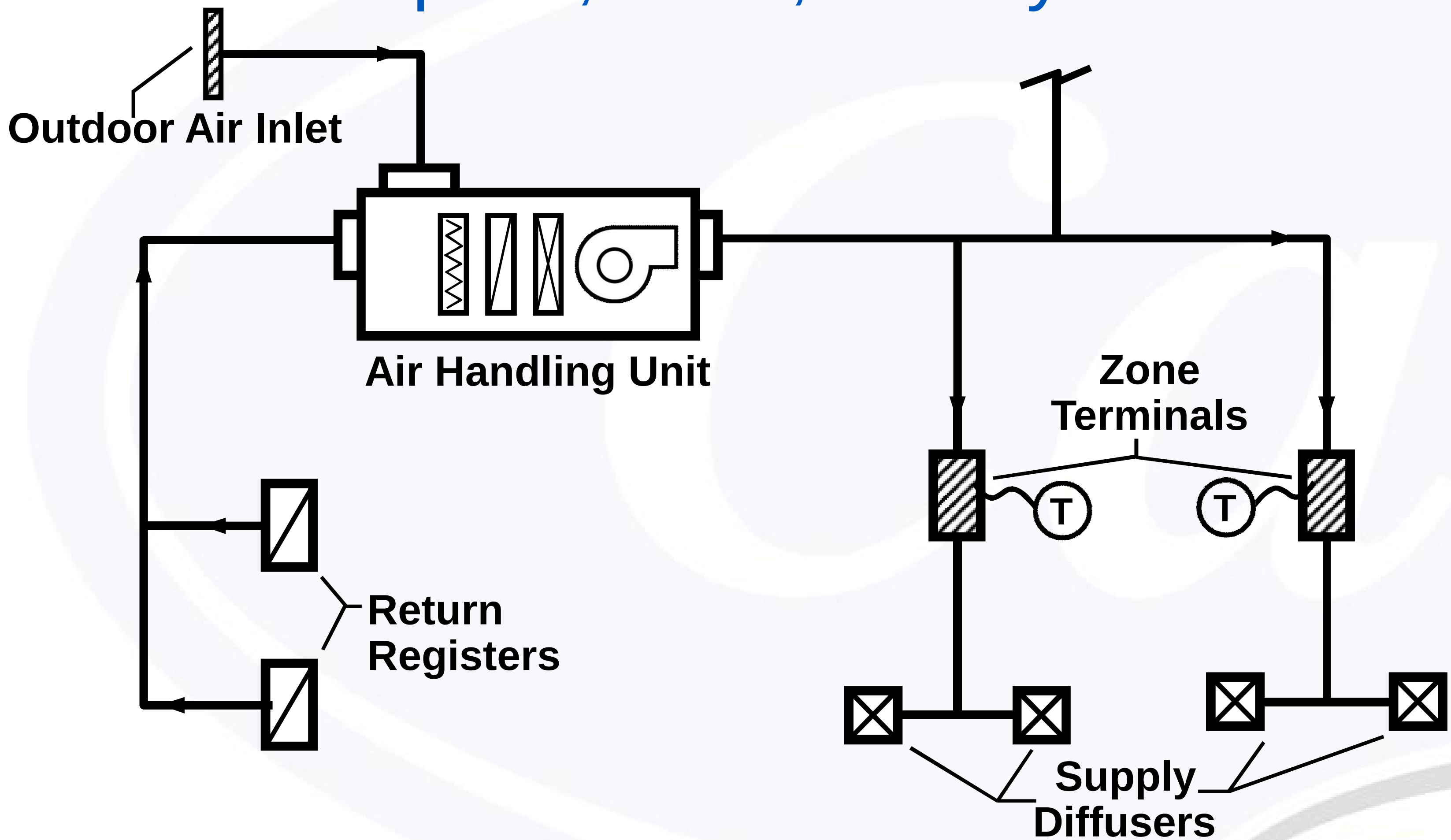
Design Step 2

Perform Cooling and Heating Load Estimates

- Accurately enter the building info
- Set system parameters for block, zone, and space loads
- Run loads

Design Step 3

Determine Space, Zone, and System Airflows



Design Step 4

Select Duct Material, Shape, and Insulation

- Cost-effective material to fit the conditions
- Round, rectangular, or flat oval to fit the space and for efficient installation
- Adequate insulation to conserve energy and avoid condensation

Common Duct Material Applications

Duty / Material	Galvanized Steel	Carbon Steel	Stainless Steel	Aluminum	Fiberglass Board	FRP	PV Steel	Gypsum Board
HVAC	X				X			
Flues		X						
Moisture-laden			X	X				
Kitchen		X	X					
Fume Hood			X			X	X	
Air Shafts	X							X
Underground							X	

FRP = Fiberglass Reinforced Plastic

PV Steel = PVC-coated steel

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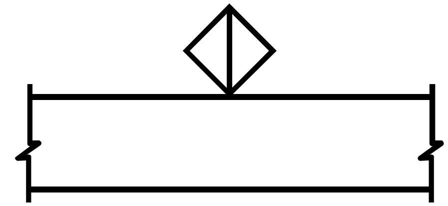
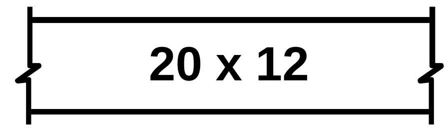
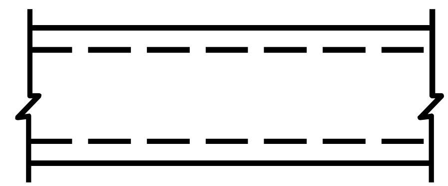
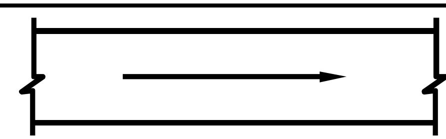
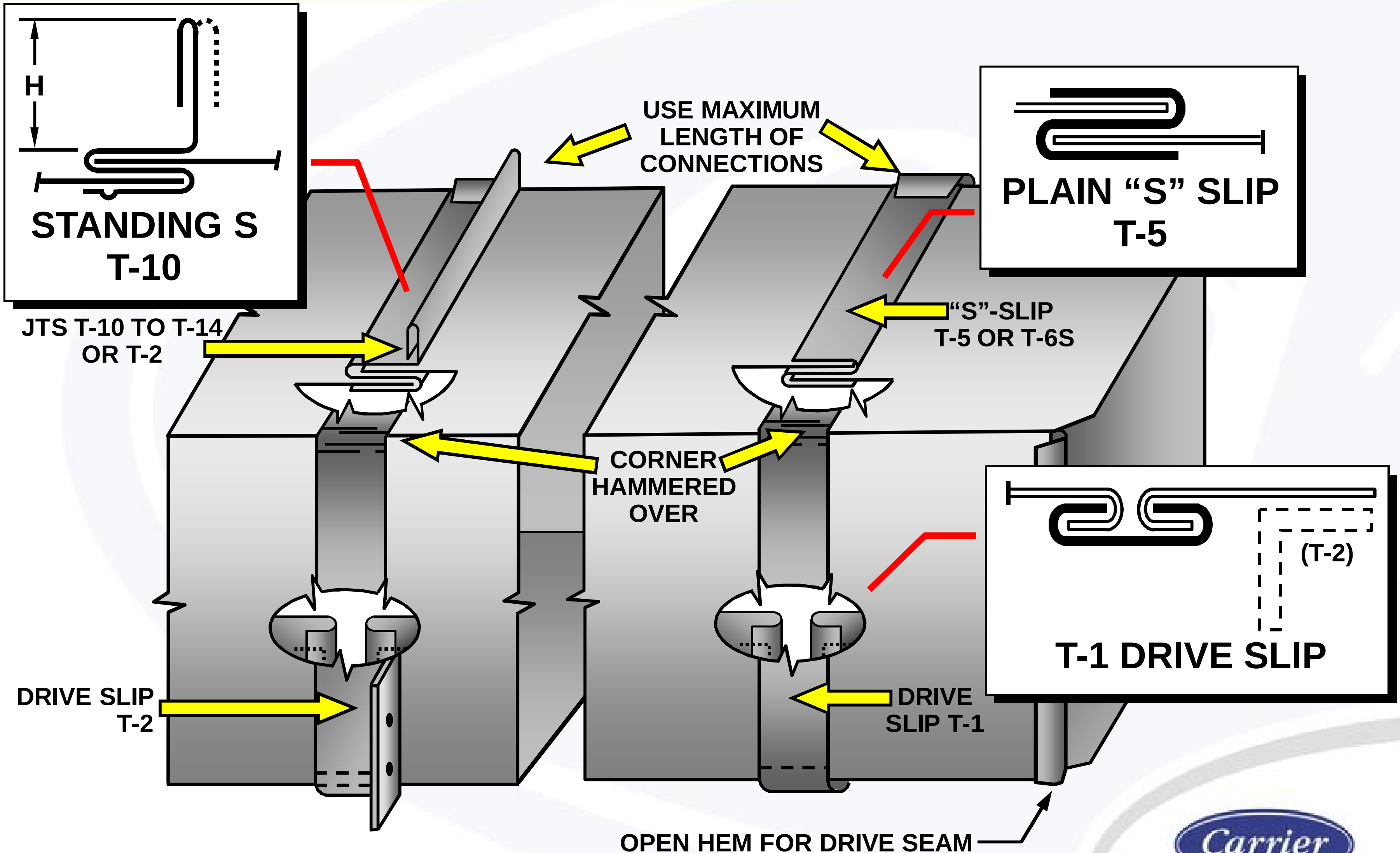
Showing Pressure Class

SYMBOL MEANING	SYMBOL
POINT OF CHANGE IN DUCT CONSTRUCTION (BY STATIC PRESSURE CLASS)	
DUCT (1ST FIGURE, SIDE SHOWN 2ND FIGURE, SIDE NOT SHOWN)	
ACOUSTICAL LINING DUCT DIMENSIONS FOR NET FREE AREA	
DIRECTION OF FLOW	

Duct Assembly Joints



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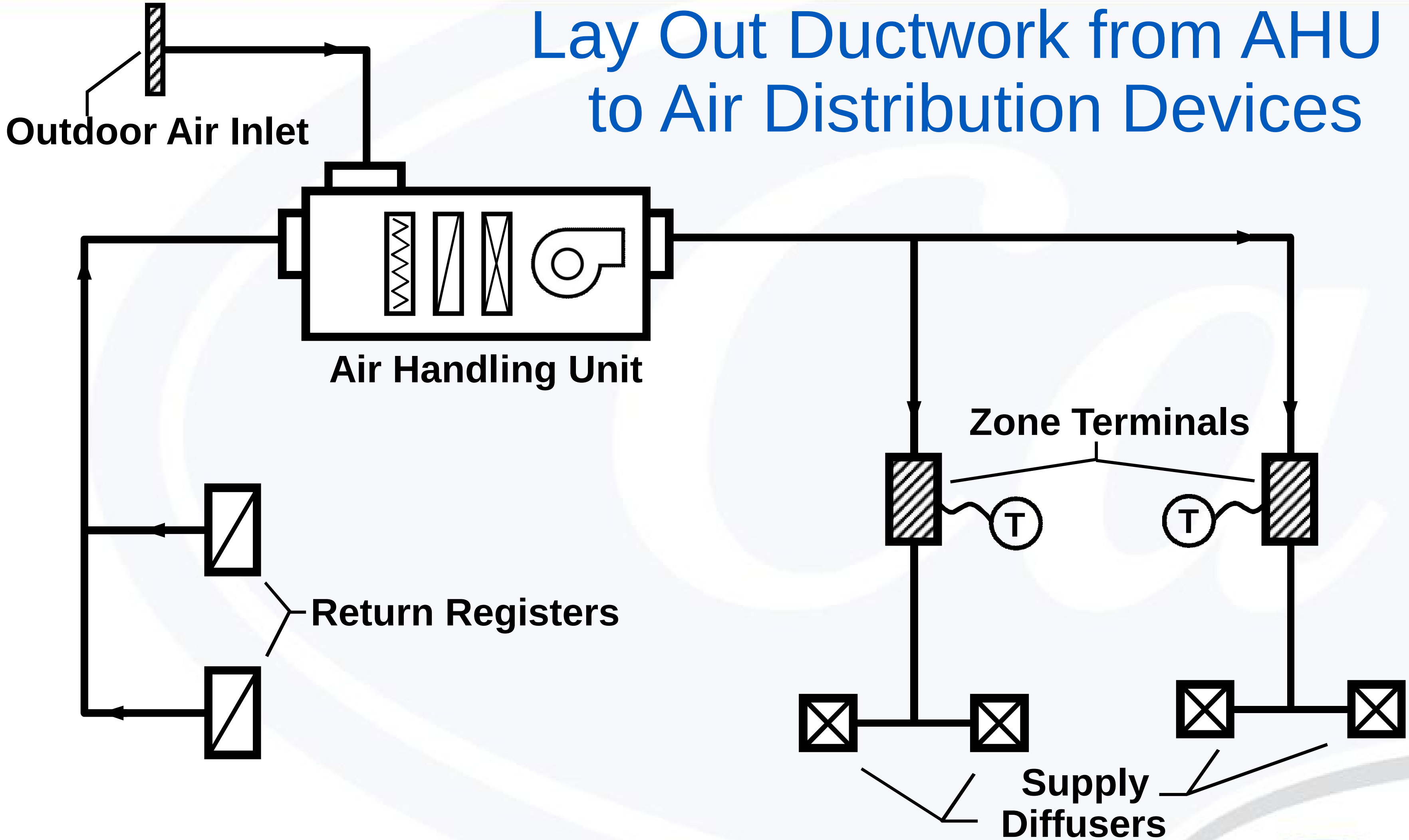
Duct Design Process Steps 5-9

1. Determine Number of Zones
2. Perform Heating and Cooling Estimate
3. Determine Room / Zone Airflow Quantities
4. Select Duct Material, Shape, and Insulation
5. Layout Ductwork from AHU to Diffusers
6. Summarize Airflows and Label Ducts
7. Size Ducts from Fan Outlet to Diffusers
8. Calculate Air System Pressure Losses
9. Select Fan and Adjust System Pressures

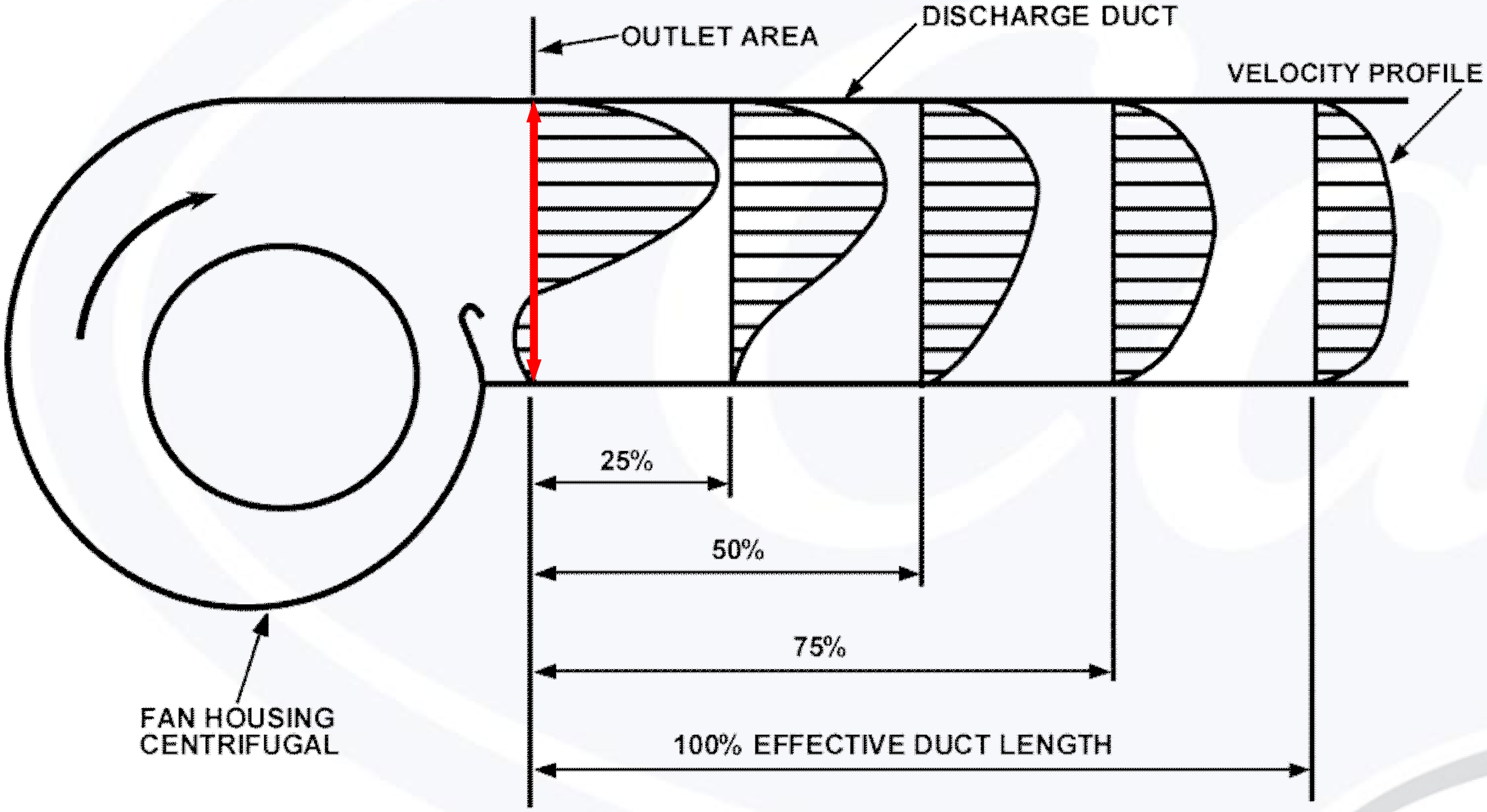
Design Step 5

Lay Out Ductwork from AHU to Air Distribution Devices

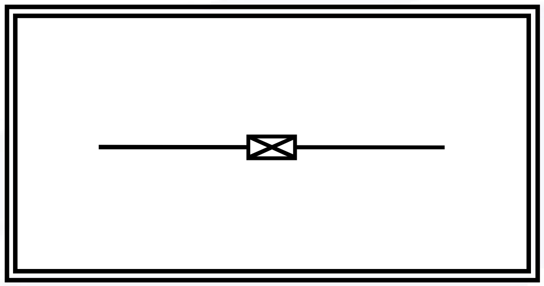


System Effect

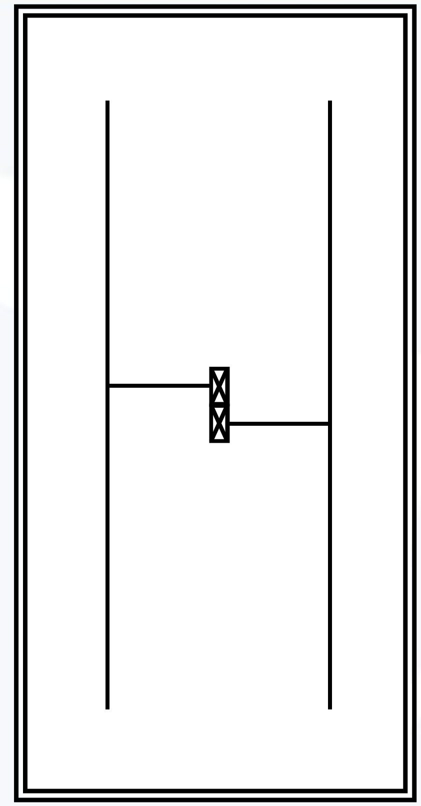
100% EFFECTIVE DUCT LENGTH = A MINIMUM OF 2½ DUCT DIAMETERS. FOR 2500 FPM OR LESS. ADD 1 DUCT DIAMETER FOR EACH ADDITIONAL 1000 FPM.



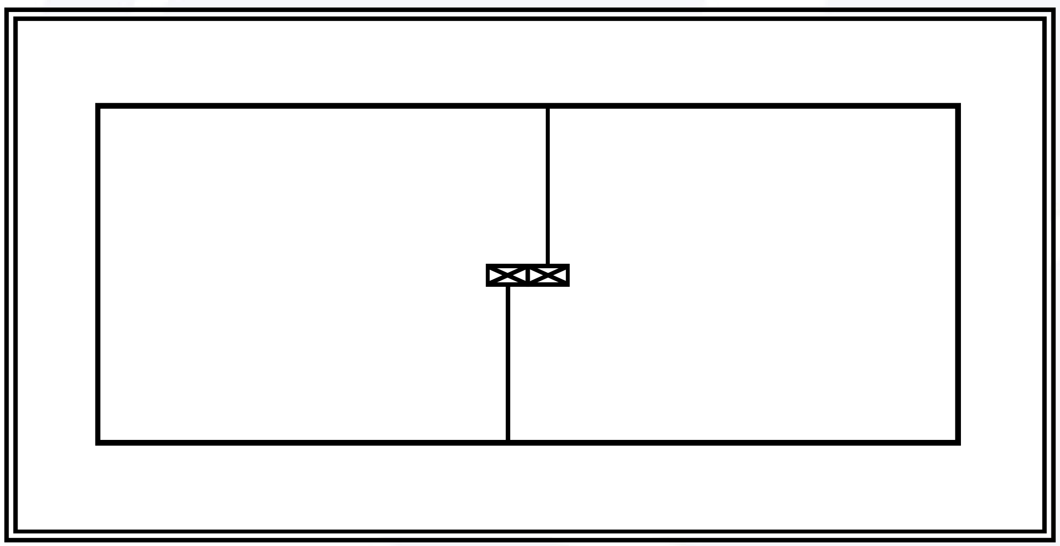
Trunk Layout to Fit the Building



“Spine” Duct Layout



“H” Pattern Duct Layout



“Loop” Duct Layout

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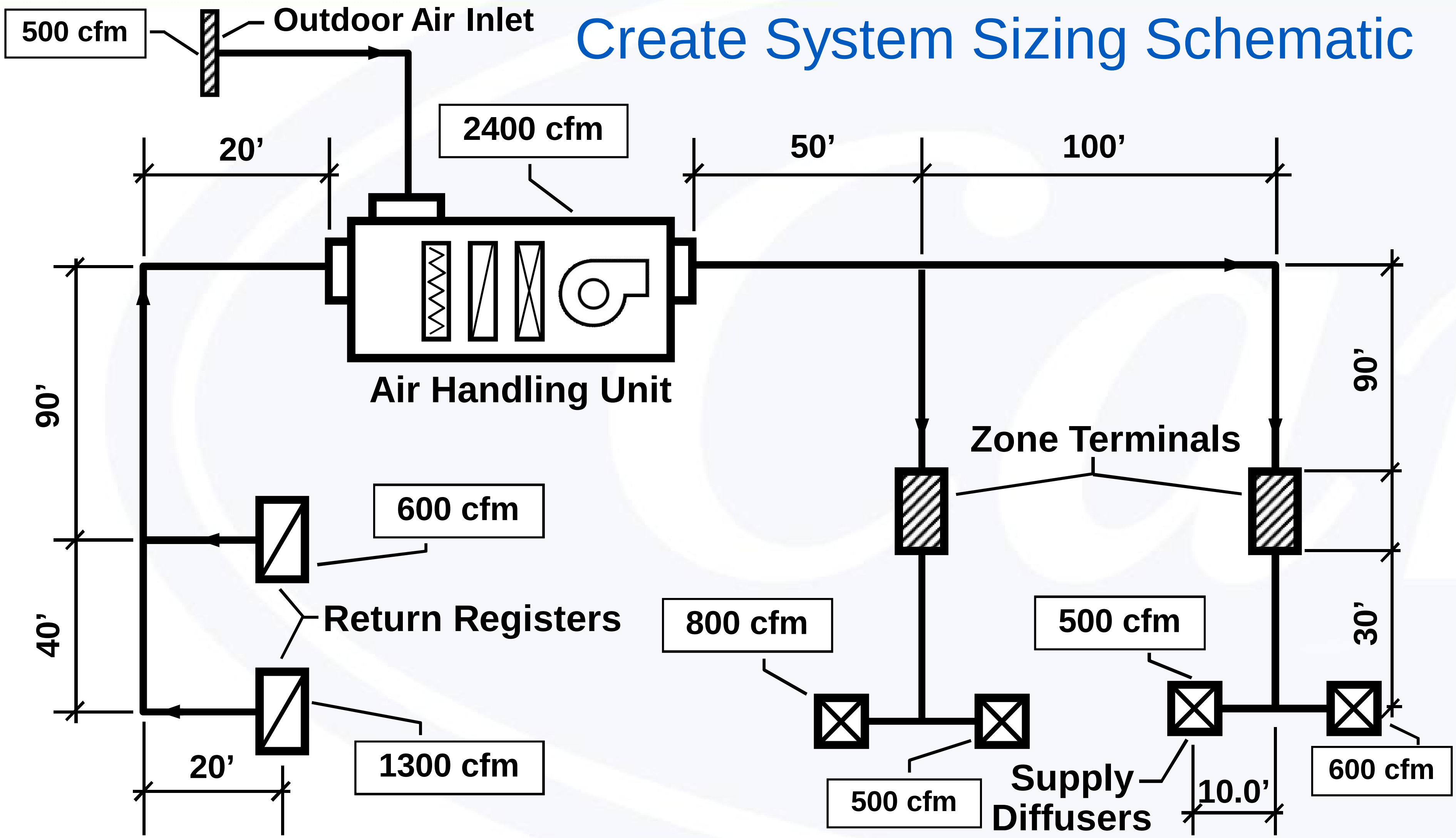
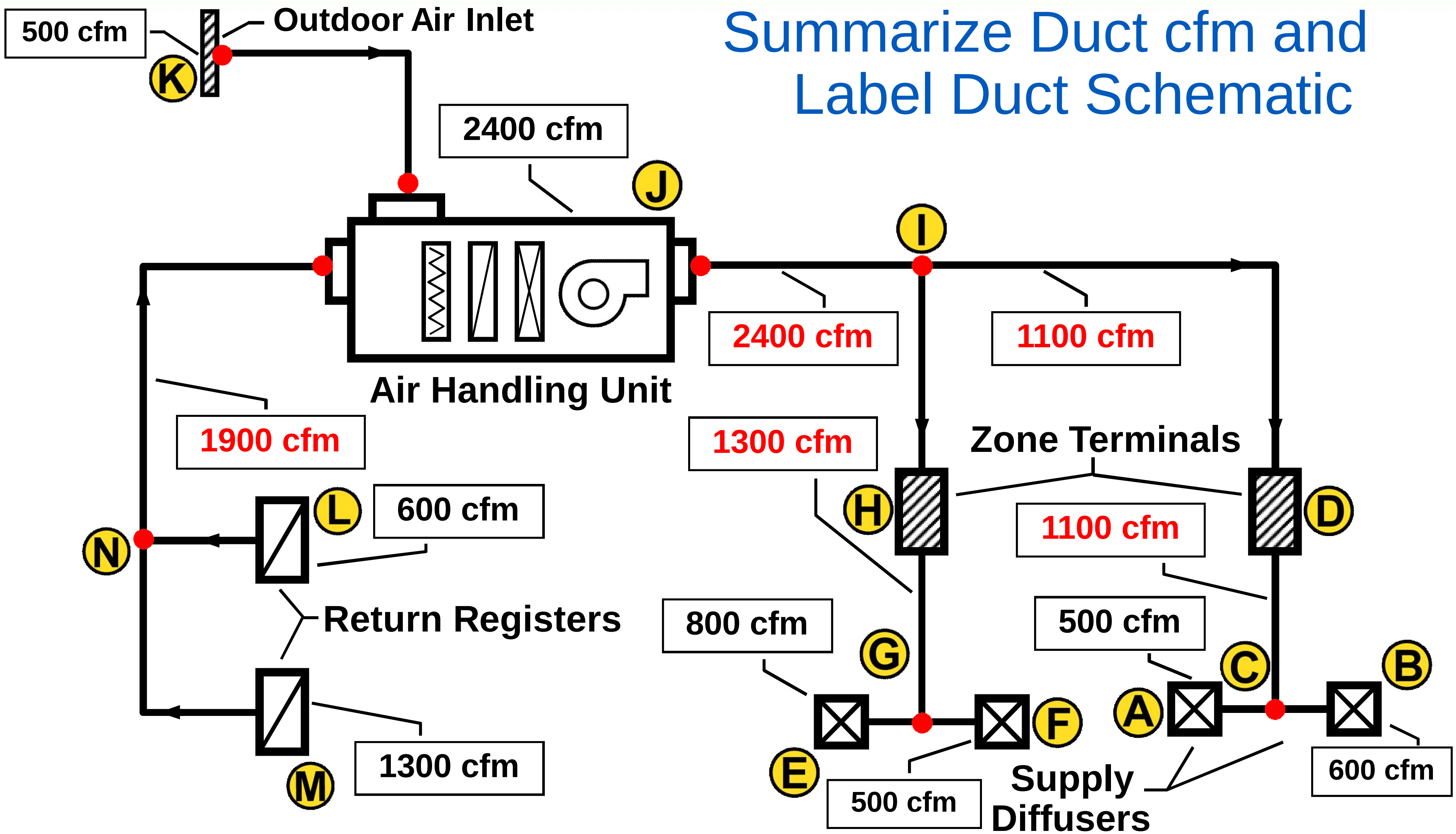
Design Step 6

Create System Sizing Schematic



Design Step 6

Summarize Duct cfm and Label Duct Schematic



Design Step 7

Size Ductwork from Fan to Extremities

- Pick an initial velocity
- Size duct sections using equal friction
- Pick efficient fittings
- Tabulate results in a Duct Sizing Worksheet

Duct Sizing Worksheet

Duct Run From -To	Duct Section (element)	Lining (in.)	Insul. (in.)	Other Item	Airflow	Velocity in Round duct (fpm)	Velocity Pressure P_V	Fitting Value n	Length (ft) L	Equiv. Length (ft) EL	Material Correction Factor	Friction Loss f per 100' duct	Friction Loss (in. wg)	Known Loss (in. wg)	Round Duct Size (in.)	Equivalent Rectangular Size ($W \times H$)	Total Item Loss (in. wg)	Cumulative Loss (in. wg)
A-E	A-B	-	1	-	7500	1500	0.140	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	E	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.134
A-F	A-B	-	1	-	7500	1500	0.014	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	B-C	-	1	-	5000	1400	0.122	-	30	-	-	0.095	0.029		25.7	28 x 20	0.029	0.063
	B	-	1	TRANS	5000 / 5000	1040 / 1400	0.062 / 0.122	1.02	-	-	-	-	0.061	-50%	-	40 x 20 / 28 x 20	0.031	0.094
	F	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.194
A-G	A-B	-	1	-	7500	1500	0.140	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	B-C	-	1	-	5000	1400	0.122	-	30	-	-	0.095	0.029		25.7	28 x 20	0.029	0.063
	B	-	1	TRANS	5000 / 5000	1040 / 1400	0.062 / 0.122	1.02	-	-	-	-	0.061	-50%	-	40 x 20 / 28 x 20	0.031	0.094
	C-D	-	1	-	2500	1200	0.096	-	20	-	-	0.10	0.02	-	20.7	16 x 20	0.02	0.114
	C	-	1	TRANS	2500 / 2500	715 / 1200	0.032 / 0.096	1.02	-	-	-	-	0.065	-50%	-	28 x 20 / 16 x 20	0.033	0.147
	G	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.247

NOTES: All duct sizes indicated are inside clear dimensions.

LARGEST STATIC PRESSURE LOSS (in. wg) 0.247

FOR RUN = A - G

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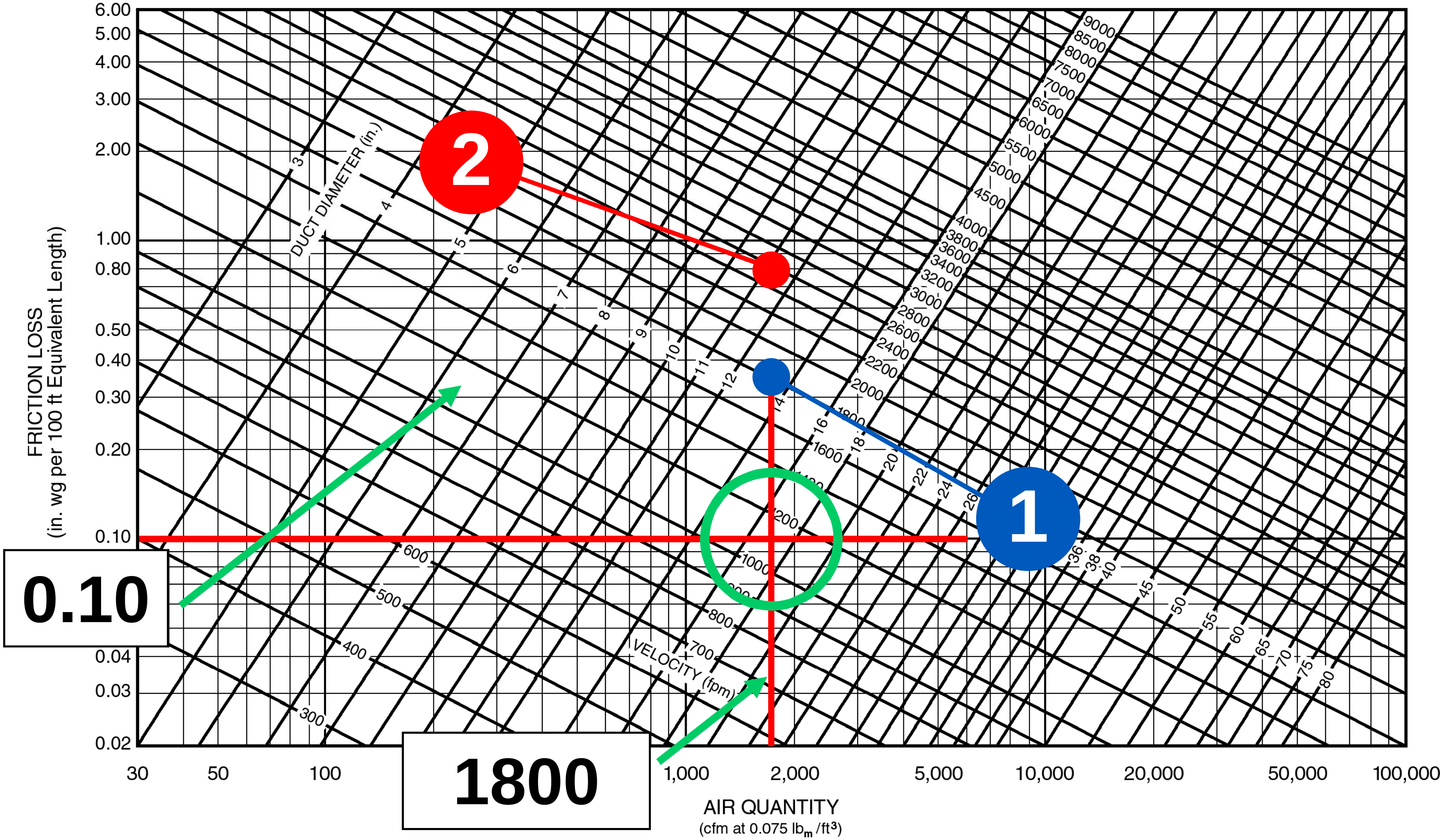
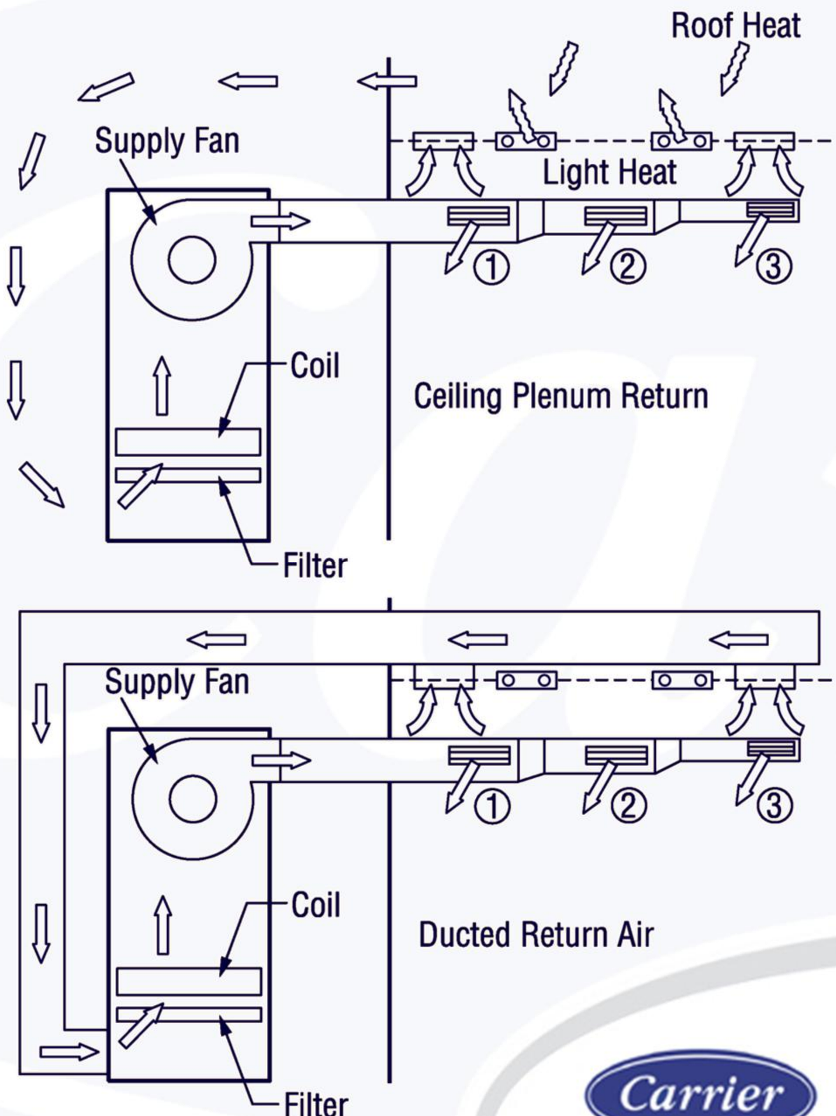
Round Duct Friction Loss Chart



Ceiling Plenum and Ducted Return

- Some buildings use ceiling plenum return.
- Reduce duct cost.
- Reduce pressure drop.



Design Step 8

Calculate Air System Pressure Losses

- Summarize losses for greatest pressure loss circuit or run
- This is not always the longest run, look at terminal and diffuser losses
- Double-check that sizes will fit into the space available.

Design Step 9

Select Fan and Adjust System Airflows

- Add safety factor to the total external pressure drop
- For exhaust/supply fan selection, external static pressure drop is equal to total static pressure drop
- Use external static pressure for AHU/RTU/FCU

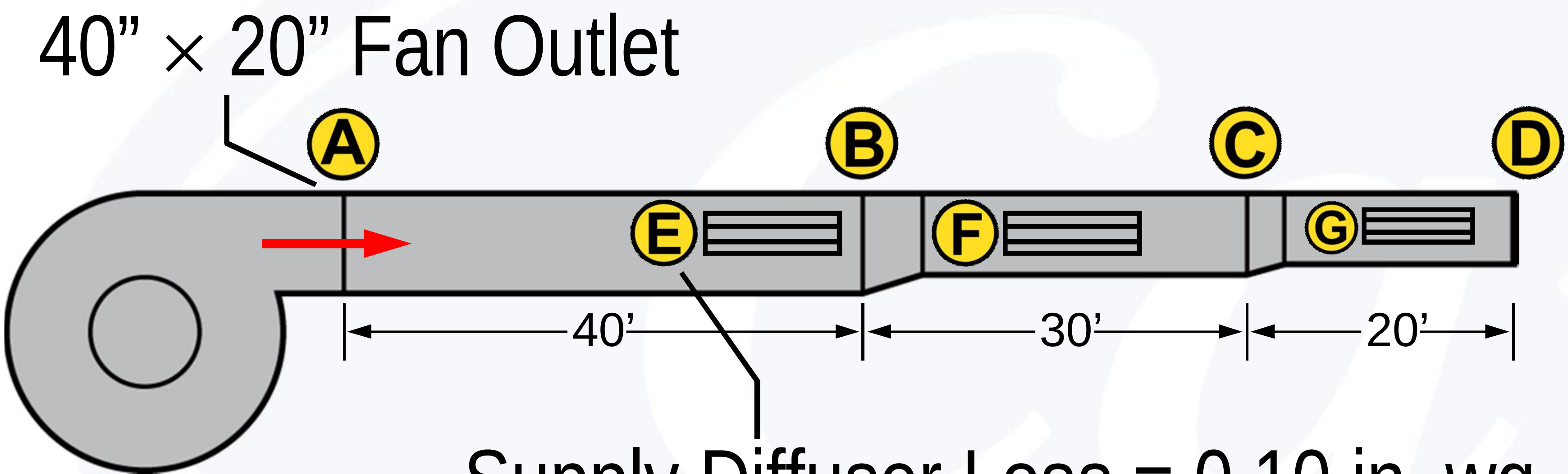
Design Step 9

Select Fan and Adjust System Airflows

- Evaluate if the static pressure makes sense
- Fine tune air distribution device or air path to minimize pressure drop

Example 3 – Equal Friction Sizing

Using the Duct Friction Table



Supply Diffuser Loss = 0.10 in. wg
@ 2500 cfm each

Duct Sizing Worksheet

Duct Run From -To	Duct Section (element)	Lining (in.)	Insul. (in.)	Other Item	Airflow	Velocity in Round duct (fpm)	Velocity Pressure P_V	Fitting Value n	Length (ft) L	Equiv. Length (ft) EL	Material Correction Factor	Friction Loss f per 100' duct	Friction Loss (in. wg)	Known Loss (in. wg)	Round Duct Size (in.)	Equivalent Rectangular Size $(W \times H)$	Total Item Loss (in. wg)	Cumulative Loss (in. wg)
A-E	A-B	-	1	-	7500	1500	0.140	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	E	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.134
A-F	A-B	-	1	-	7500	1500	0.014	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	B-C	-	1	-	5000	1400	0.122	-	30	-	-	0.095	0.029		25.7	28 x 20	0.029	0.063
	B	-	1	TRANS	5000 / 5000	1040 / 1400	0.062 / 0.122	1.02	-	-	-	-	0.061	-50%	-	40 x 20 / 28 x 20	0.031	0.094
	F	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.194
A-G	A-B	-	1	-	7500	1500	0.140	-	40	-	-	0.085	0.034	-	30.5	40 x 20	0.034	0.034
	B-C	-	1	-	5000	1400	0.122	-	30	-	-	0.095	0.029		25.7	28 x 20	0.029	0.063
	B	-	1	TRANS	5000 / 5000	1040 / 1400	0.062 / 0.122	1.02	-	-	-	-	0.061	-50%	-	40 x 20 / 28 x 20	0.031	0.094
	C-D	-	1	-	2500	1200	0.096	-	20	-	-	0.10	0.02	-	20.7	16 x 20	0.02	0.114
	C	-	1	TRANS	2500 / 2500	715 / 1200	0.032 / 0.096	1.02	-	-	-	-	0.065	-50%	-	28 x 20 / 16 x 20	0.033	0.147
	G	-	-	OUTLET	2500	-	-	-	-	-	-	-	-	0.10	-	-	0.10	0.247

NOTES: All duct sizes indicated are inside clear dimensions.

LARGEST STATIC PRESSURE LOSS (in. wg) 0.247

FOR RUN = A - G

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BOOK MENU

SECTION 5

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Summary

BOOK MENU

Turn to the Experts.

Summary

- Cost-effective duct design is as much an art as it is a science.
- Bernoulli's Law is used to explain the relationship between velocity and static pressures.
- Use of straight-forward layouts with efficient fittings is critical in duct design.
- Friction loss charts and duct calculators are important tools in reinforcing duct design principles and improving the duct design process.

Work Session 1

Work Session 1 – Fundamentals

1. Define the following terms:

   Total Pressure: ____

   Velocity Pressure: ____

   Static Pressure: ____

2. Which of the following affects duct friction loss? (Choose all that apply): ______________

   a.) duct size
   b.) duct length
   c.) thickness of duct wrap
   d.) air velocity
   e.) duct construction material
   f.) fitting type

3. True or False? A fan begins to convert static pressure into velocity pressure in the first few feet of supply duct. ________________

what type of ene

Thank You

This completes the presentation.

TDP-504 Duct Design Level 1 Fundamentals

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